TOWARDS BUILDING OCCUPANTS POSITIONING: TRACK AND TRACE FOR OPTIMAL PROCESS CONTROL

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ABSTRACT

Building occupancy information is a crucial factor that should be considered in the control strategy of building operations for improved energy efficiency and occupant comfort. As occupancy is stochastic and challenging to measure, a number of real-time occupancy detection systems comprising multiple sensors within a wireless network (WSN) using technologies such as radio frequency identification (RFID) and WIFI enabled devices have been proposed for use in large commercial office buildings. However due to high deployment cost and need for management of additional infrastructure for these systems, its application in demand driven control of heating, ventilation and air conditioning (HVAC) is limited notwithstanding the accruable worthwhile energy saving potentials. In this paper, some of this new technologies are briefly discussed and compared with opportunistic implicit building infrastructures which can be exploited for real-time demand driven HVAC control based on the application of the Kesselring decision support method.

Keywords; demand-driven HVAC control, comfort, energy.

INTRODUCTION

Energy consumption in commercial office buildings has been increasing rapidly, rising by 70% between 1980 and 2005 in the US alone (DOE 2008). As commercial office buildings are more sophisticated and better equipped for more flexible control and actuation possibilities, dynamic control of building Lighting, Heating, Ventilation and Air conditioning (LHVAC) systems in relation to actual building occupancy profile presents an opportunity for more efficient use of energy for improvement of occupants comfort. Occupants presence and behaviour in buildings have been shown to have a significant effect on energy consumption (Page et al, 2007) and various authors and researcher have through simulations (Oldewurtel et al, 2013, Li et al, 2012) and field experiments (Dong et al, 2010 Agarwal et al, 2011) demonstrated the energy saving potentials of tracking and localizing occupants in thermal zones within commercial office buildings. For efficient control and allocation of comfort resources, it is desirable to determine the number of occupants in a thermal zone within the shortest possible time-span in order to provide adequate comfort for the occupants. It is as well desirable and has been demonstrated (Li et al, 2012) that energy use can reduced if L-HVAC systems are operated using actual building occupancy information. However occupancy in commercial office buildings is stochastic; building occupancy is difficult to simply infer solely from building function and type as there are high tendencies for a buildings usage to change with time and occupants might over time display varying patterns of presence (Mahdavi, 2011). Advancement in technology has made the realization of real-time occupancy possible. A number of wireless sensor network (WSN) systems have been developed, however the cost of deployment and the management of additional sensing infrastructure still remains significant (Lakshmi et al, 2012). There is now a growing consideration on the use of existing building infrastructures (Li et al, 2005, Melfi et al, 2011, Martani et al, 2011, Lakshmi et al, 2012) rather than explicit systems for occupancy detection in commercial buildings. Wireless local area networks (WLAN), cameras and motion sensors are implicit components which can be exploited to obtain varying degrees of occupancy resolution in commercial office buildings for both individualized and non-individualized functions.

Individualized systems are capable of identifying particular occupants while non-individualized systems are not able to identify particular occupants (Li et al, 2012). In subsequent sections of this paper, as a result of the importance of occupancy detection and the energy saving potential of demand driven LHVAC systems, some of these implicit systems are briefly discussed. A comparison of these systems using the Kesselring decision support method based functions and realisation is also discussed as part of a broader research goal to develop new control strategies that would improve the human–in-the–loop interactions with building systems.

SHORT REVIEW

PASSIVE INFRARED SYSTEMS (PIR)

Infrared (IR) technology has been exploited in many commercial applications making it inexpensive and readily available. In building energy management, PIR sensors are most often used in lighting systems and energy savings of between 10 to 45% have been shown to be obtainable from the use of PIR sensors in lighting systems control (Melfi et al, 2011). Want et al (1992) experimented the use of PIR sensors for individualized detection by deploying an active badge network comprising 100 badges and 200 sensors communicating the location of building occupants through a wired network to a central server using infrared technology. Information about occupants whereabouts was potentially available from any terminal on the network and could be integrated to provide extended functionalities such as demand driven HVAC control. For actual demand driven control of HVAC systems in a large university building, Agarwal et al (2010) and Agarwal et al (2011) utilized a combination of both PIR sensors and magnetic door sensors to determine real-time occupancy in rooms on a whole university floor. The output of the combined sensor was transmitted via the universities wireless network to a central server which communicated the status of the room to the building management system for demand driven HVAC control. Using low-cost devices and the existing infrastructure, energy savings of up to 15.73% and 12.85% for HVAC electricity and thermal energy use respectively were recorded. Unlike the active badge system which could be used for individualized functions, the system could detect occupancy, but could neither count nor identify occupants.

VISION BASED SYSTEMS.

As cameras are also a common feature in large commercial establishment for security purposes, researchers have explored its use also in occupant localization within building thermal zones. Erickson et al (2013) proposed and developed a system based on wireless network of cameras called OPTNet 22 wireless camera nodes with on board image processing algorithm capable of compressing the captured data for efficient transmission to the processing server were installed along hallways in an office building. The developed system was able to detect transition with an accuracy of up to 94%. In order to limit errors due to false measurement, the system was combined with a wireless network comprising PIR sensors similar to the system developed by Agarwal et al (2011). By dynamically controlling the buildings HVAC system using the real-time occupancy data, it was shown that energy savings of 26% was possible while maintaining comfort. Some other vision based systems have also been proposed (Benezeth et al, 2011, Han et al, 2012) for identification of individual occupants within a space; however, these systems require significant processing power to stream real-time images wirelessly for real-time HVAC control. For most vision based systems, the major drawbacks are still privacy, cost and maintenance. Also line of sight obstructions significantly affect the accuracy of this systems.

WIFI ENABLED DEVICES

WIFI enabled devices such as personal computers, mobile phones and personal digital assistants (PDAs) are very common devices available in commercial office buildings and have as well been explored for both

individualized and non-individualized functions. Martani et al (2012) explored the use of WIFI enabled devices in two university buildings to survey human occupancy at different levels of granularity for non-individualized functions. The number of WIFI devices actively connected to the Wireless local area network (WLAN) were used as an estimate of occupancy in rooms. However since WIFI signals are able to penetrate walls error due to overlapping connections and inconsistent connectivity seriously affected its performance. Melfi et al (2011) also explored the use of WIFI enabled systems within a building for both individualized and non-individualized functions but encountered the same challenge; overlapping connections and inconsistent connectivity of WIFI enabled devices. In both cases, it was shown that an estimate of occupants position and count in a room was possible using WIFI enabled devices within a building network but no actual connection was made with the building HVAC system for demand driven control. For individualized functions, Khoury and Kamat (2009) explored the use of a commercially available dedicated WIFI-based positioning system which uses dedicated clients, the system however relies heavily upon many components using separate infrastructure.

RADIO FREQUENCY IDENTIFICATION SYSTEMS (RFID)

The RFID system uses active tags and multiple readers to triangulate the position of tags. ID badge scanning systems are also commonly used in large commercial office buildings and can be used to identify particular occupants for individualized functions. The feasibility of this system in HVAC control in a large office building was explored by Li et al, (2012) using battery powered RFID tags, mobile occupants were identified and tracked over a period of time. The collected data was used in calibrating an occupancy prediction model but the author showed it was possible to make use of the system for real-time localization for demand driven HVAC control. Like the system deployed by Khoury and Kamat (2009) the system relies upon heavy instrumentation requiring separate infrastructure.

DISCUSSION

The different techniques for detection of the human position are valued on how it functions and can be realized as projected by the Kesselring method. By applying this method singularities are made visible, which are difficult with regular tables such as bar diagrams (Zeiler et al, 2007). The functioning criteria are based on the occupancy resolution divided into occupant, temporal and spatial resolution, as proposed by (Melfi et al, 2011). Occupant resolution relates to the information obtainable from the system;

- *Occupancy* – a zone has at least one person in it;
- *Count* – how many people are in a zone;
- *Identify* – who they are;
- *Activity* – what they are doing.

Spatial resolution refers to the granularity of the measurement system while temporal resolution refers to the shortest time span in which changes in both occupant and spatial resolution can be detected by the system.

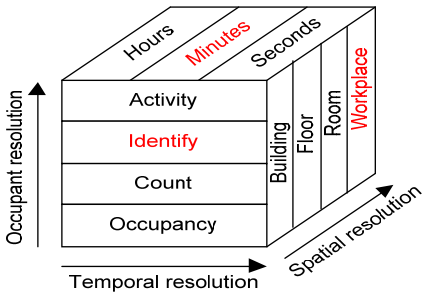

Figure 1 Occupancy resolution with the accuracy of the temporal, occupant and spatial resolution, modified from [Melfi et al, 2011]

The realization criteria are: costs, implementation, and adaptability. For both the functioning and realization, a weighting factor is added to the score. Regarding the techniques discussed, the following can be concluded:

- All the systems are capable to provide the same spatial resolution and temporal resolution.
- For occupant resolution PIR sensors scored higher been able to sense activity better than the other system.

Kesselring assessment

Decision support methods are intended to help designers in making decisions. As people are limited in their capacity to process information, evaluation should be conducted in terms of each criterion separately. Subsequently, the values determined have to be aggregated into a score for the 'overall' value of each alternative. Kesselring developed a visualization technique, with which different variants can be compared with each other.

Within the Kesselring method, the criteria for the requirements are separated into a category for realization and a category for functionality. By doing this the strong point can be seen in the so called S-(Stärke) diagram. To visualize the scores the criteria of the program of requirements are separated in groups with relating requirements. The first group of criteria has to do with the functionality of the design and the other group of criteria with the realization, see table 1.

Table 1 Kesselring assessment

			PIR-based		Vision-based		WIFI-based		RFID-based	
	Factor	Max	Score	Total	Score	Total	Score	Total	Score	Total
Function			(max 3)							
Spatial resolution										
Floor	1	3	2	2	2	2	2	2	2	2
Room	2	6	4	8	4	8	4	8	4	8
Workplace	3	9	3	9	3	9	3	9	3	9
Temporal resolution										
Minutes	1	3	3	3	3	3	3	3	3	3
Seconds	3	9	2	6	2	6	2	6	2	6
Occupant resolution										
Occupancy	1	3	3	3	3	3	3	3	3	3
Count	2	6	3	6	3	2	3	6	3	6
Identify	3	9	3	9	3	9	3	9	3	9
Activity	1	3	2	2	1	1	0	0	0	0
Total points		51		48		43		46		46
Percentage		**100**		**94**		**84**		**90**		**90**
Realization			(max 3)							
Costs	1	9	5	5	3	3	6	6	4	4
Implementation	2	6	3	6	2	6	4	8	3	6
Adaptability	2	6	3	6	2	4	3	6	2	4
Total points		21		17		13		20		14
Percentage		**100**		**81**		**62**		**95**		**67**

The total score of the functional and realization criteria is expressed as a percentage of the maximum score to gain. In the diagram the percentage of the criteria for functionality is set out on the y- axis and the percentage of the criteria for realization on the x-axis (figure 3). The best variants lie near the diagonal and have high scores. It is wise to set values to limit the selection area. A practical suggestion is to divide the area in two with a minimum border set by the x- and y-value of 40 and by (x+y)-value of 55% (figure 3). The Kesselring

method makes singularities visible, whereas that in the normal choice tables and bar diagrams only could be retrieved with much effort. In the Kesselring diagram it is easy to see if the improvements must take place in the functionality or on the realization side.
From this comparison the results within Fig. 3 clearly indicate that RFID is the most promising technology to apply for tracing and tracking of occupants within a building. For realization: WIFI systems and PIR systems had the highest scores due to low cost of implementation

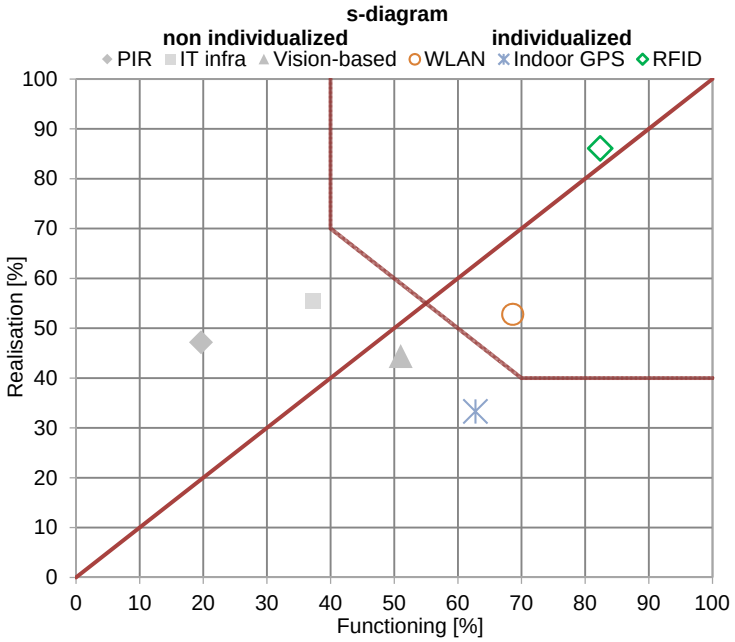

Figure 3 S-diagram of Kesselring showing the evaluated functional and realization aspect for the 3 individualized and 3 non-individualized techniques for detection of the user indoor position

CONCLUSIONS

An efficient building control strategy should take occupancy into consideration. Worthwhile energy savings can be obtained in large commercial office buildings through demand driven LHVAC control as demonstrated. However most commercial buildings still operate according to assumed occupied and unoccupied periods despite findings from actual office building occupancy showing that average occupancy in office buildings represents a third of their design occupancy even at peak times (Klein et al, 2012, Mahdavi 2011). In this study, four opportunistic detection systems capable of both individualized and non-individualized functions were discussed. From the assessment, PIR and WIFI systems had the highest scores. Though WIFI systems have a high measurement uncertainty, the use of WIFI enabled systems in combination with PIR sensors shows great potential for both individualized and non-individualized functions. Also as PIR sensors are low cost devices and considering the fact that WIFI networks are common in every commercial office building the cost of deploying such a system is significantly lesser than systems such as RFID and vision based systems.

ACKNOWLWDGEMENT

This project is financially supported by Kropman Building Service contracting.

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